

NASA Technical Memorandum 106978

1N-76

56589

p. 12

# Space Qualified Hybrid Superconductor/ Semiconductor Planar Oscillator Circuit

F.A. Miranda, C.M. Chorey, R.R. Romanofsky, and K.B. Bhasin  
*Lewis Research Center*  
*Cleveland, Ohio*

Prepared for the  
Low Temperature Electronics and High Temperature Superconductivity Symposium  
sponsored by the Electrochemical Society  
Reno, Nevada, May 21-26, 1995



National Aeronautics and  
Space Administration

(NASA-TM-106978) SPACE QUALIFIED  
HYBRID SUPERCONDUCTOR/SEMICONDUCTOR  
PLANAR OSCILLATOR CIRCUIT (NASA.  
Lewis Research Center) 12 p

N95-30703

Unclass

G3/76 0056589

# **SPACE QUALIFIED HYBRID SUPERCONDUCTOR/SEMICONDUCTOR PLANAR OSCILLATOR CIRCUIT**

**F. A. Miranda, C. M. Chorey, R. R. Romanofsky, and K. B. Bhasin**  
National Aeronautics and Space Administration  
Lewis Research Center, Cleveland, Ohio 44135

## **ABSTRACT**

We report on the space qualification of a hybrid superconductor/semiconductor planar local oscillator (LO) at 8.4 GHz. This oscillator was designed, fabricated, and tested as a component for the High Temperature Superconductivity Space Experiment II (HTSSE-II). The LO consisted of a GaAs MESFET and microstrip circuitry patterned onto a  $\text{YBa}_2\text{Cu}_3\text{O}_{7.8}$  high-temperature-superconducting (HTS) thin film on a  $1.0 \times 1.0 \text{ cm}^2$  lanthanum aluminate ( $\text{LaAlO}_3$ ) substrate. At 77 K, this oscillator achieved power output levels of up to 10 dBm into a  $50 \Omega$  load. When incorporated into a full cryogenic receiver, the LO provided output powers within 0.0-3.0 dBm with less than 50 mW of dc power dissipation. Space qualification data on the sensitivity of the HTS films to the processing steps involved in the fabrication of HTS-based components are presented. Data on ohmic contacts, strength of wire bonds made to such contacts, and aging effects, as well as vibration test results are discussed.

## **INTRODUCTION**

Stable microwave oscillators, typically realized by crystal oscillators or dielectric-resonator-stabilized oscillators (DRO), can now be implemented in planar integrated form using high-temperature-superconductor (HTS) thin films (1,2). An HTS-based oscillator offers advantages such as reduced circuit complexity and increased reliability associated with integrated circuits while retaining performance levels comparable to those obtained with the DRO's up to the Ku-band frequency range. Typical values of the unloaded quality factor ( $Q_0$ ) for DRO's are in the range of 10,000 to 20,000. At 77 K, planar HTS resonators exhibit  $Q_0$ 's near 10,000 as compared to normal metal resonators which exhibit  $Q_0$ 's of less than 1000. The high  $Q_0$ 's of the HTS-based resonators can make possible stable oscillators with low phase noise.

In this paper we report on the space qualification of a hybrid superconductor/semiconductor planar microwave local oscillator (LO) at 8.4 GHz. This oscillator was designed, fabricated, and tested as a component for the High Temperature

Superconductivity Space Experiment II (HTSSE-II) (3). In particular, we present data on issues such as repeatability in the deposition and processing of the HTS films, metal contact formation, wire bonding, and overall circuit endurance to fabrication and assembly procedures, including vibration tests. Examples of variations observed in starting films and finished circuits will be presented.

## EXPERIMENTAL

The LO consists of a 1.0x1.0 cm, 20 mil thick, lanthanum alluminate ( $\text{LaAlO}_3$ ) substrate coated with a 400 nm thick  $\text{YBa}_2\text{Cu}_3\text{O}_{7.8}$  (YBCO) superconducting thin film and a gold ground plane. Films for the LO were deposited by off-axis magnetron sputtering and were obtained from a commercial vendor. The zero dc resistance temperature ( $T_c$ ) for these films was measured using a standard four point probe technique;  $T_c$ 's  $\geq 86$  K were typically measured. The passive elements of the circuit (i.e., the stabilizing resonator, reactive feedback elements, transmission lines, and dc bias lines) are realized as microstrip elements fabricated through chemical etching of the YBCO film with either Ethylenediamine Tetraacetic Acid (EDTA) or diluted Phosphoric Acid ( $\text{H}_3\text{PO}_4$ ) with a ( $\text{H}_2\text{O}:\text{H}_3\text{PO}_4$ , 100:1) concentration and standard photolithography. The active element of the reflection mode oscillator consists of a die (i.e., unpackaged) GaAs metal-semiconductor field effect transistor (MESFET) (Avantek ATF-13100GP1) which is attached to the  $\text{LaAlO}_3$  substrate using a heat cured conductive silver-based epoxy (Ablebond Ablestick 36-2). Gold bond wires (0.7 mil diameter) were used to thermosonically wire-bond the MESFET to the superconducting lines. Metallic pads were fabricated on the superconducting lines by electron beam evaporation of silver and gold with a subsequent annealing treatment in oxygen at 425°C for 50 min. Ceramic chip capacitors (1800 pF, 100 pF, and 56 pF; American Technical Ceramics, Inc.) with titanium-tungsten-nickel-gold (TiW/Ni/Au) terminations and thin film 10  $\Omega$  chip resistors (IMS Corp.) mounted next to the substrates were used to filter and de-couple the transistor bias; these were thermosonically bonded to the circuit using 1x2 mil gold ribbon. Over 20 oscillators were fabricated in our clean room facilities. Approximately 10 of these were actually assembled into working oscillators and tested. The remainder were used for other testing such as bond pull test and  $T_c$  measurements. A schematic representation of this oscillator is shown in figure 1. For the cryogenic characterization, the LO was mounted on a custom made brass test fixture and bolted to the cold finger of the second stage of a closed-cycle helium-gas refrigerator. All the measurements were performed under vacuum.

## RESULTS

The performance of the oscillator was measured at 77 K, since it is expected that the operating temperature of the cold bus for HTSSE-II will be  $77 \pm 1$  K. Typical loaded Q's

for these oscillators were approximately 1000 ( $Q_o$ 's near 6,000 were measured in our laboratory during this project). The output of the oscillator was near 8.4 GHz ( $\sim 8.39$ -8.40) with output power levels of up to 10 dBm into a 50  $\Omega$  load. When integrated into a low noise cryogenic receiver-downconverter, typical operating conditions for this oscillator resulted in a 0 to 3.0 dBm power output with less than 50 mW of dc power dissipation. At 77 K, it was observed that for gate voltages ( $V_g$ ) in the ranges of  $-0.75 \leq V_g \leq 0.0$  volts, optimum power outputs (i.e., near 10 dBm) were attained for drain voltages ( $V_d$ ) in the  $2.4 \leq V_d \leq 3.2$  volt range. As shown in figure 2, optimum frequency stabilization for this oscillator within the aforementioned  $V_g$  range was attained within  $2.2 \leq V_d \leq 3.2$  volts.

In the process of fabricating the LO circuit it was observed that because of factors such as variations in the YBCO etch rates and the YBCO materials properties, the output characteristics of individual oscillators were not identical. Variations in the output frequency were observed to be on the order of  $\pm 20$  MHz from 8.4 GHz and were bias and temperature dependent as shown in figure 2. Therefore, as part of the space qualification process required in the context of the HTSSE-II experiment, these circuits were subjected to rigorous tests which addressed repeatability in the deposition and processing of the HTS films, metal contact formation, wire bonding, and overall circuit endurance to fabrication and assembly procedures. It was shown that under identical processing conditions the properties of the HTS films degraded to varying extents. From the space qualifications point of view this imposed stringent demands on the robustness of the HTS elements of the hybrid circuit, in particular, during post-patterning processes such as the epoxy cure cycle heat treatment (necessary for the attachment of the GaAs MESFET to the substrate) and vacuum bake-out required to drive off absorbed moisture immediately prior to the hermetic sealing of the receiver package. Results of these tests, performed with magnetron sputtered (MS) as well as laser ablated (LA) YBCO thin films are shown in figure 3. For the laser ablated samples the  $T_c$  did not vary appreciably with the processing steps regardless of the chemical etching employed during patterning. These two samples belonged to the same wafer and their behavior suggests that samples with  $T_c$ 's  $\geq 90$  K are less sensitive to this type of processing. However, the sputtered samples exhibited greater sensitivity to processing as shown by the wider  $T_c$  variations. It is apparent that for MS samples step 3 appears to be a "turning-point" in the degradation of their  $T_c$ 's. The effect of the annealing in these samples was investigated further by subjecting unprocessed (i.e., unetched, unmetallized) films to the annealing cycle and monitoring their  $T_c$ . The results of this test showed a great sensitivity and random variability of the sample  $T_c$  due to the annealing process.

A very important aspect related to the integration of HTS-based components into practical microwave circuits is the formation of ohmic contacts with low contact resistance, good adhesion, and the ability to support strong wire bonding. During the

space qualification of the LO it was observed that the strength of the wire bonds made to the ohmic contacts were highly dependent on the contact fabrication process and also on the film deposition process. Wire bonds' strengths were determined by conducting pull tests as outlined in MIL-STD-883 and were performed for 0.7 mil gold wire and 1x2 mil gold ribbon. For YBCO films deposited by magnetron sputtering it was observed that the increasing bond strength correlates with the decreasing fraction of silver in the contact metallization as shown in figure 4. Only contact type 3 consistently show strengths which meet the MIL-STD-883 requirements (i.e., pull strength  $\geq 5.0$  g and  $\geq 2.0$  g for 1x2 mil gold ribbon and 0.7 diameter gold wire, respectively). The original purpose for the inclusion of the silver in the contacts was to lower the contact resistance. However, these tests indicate that the silver has an adverse effect on the bond strength.

Similar studies were also performed for samples deposited by laser ablation to determine the effect of cleaning the HTS surface prior to the contact deposition. Three processes for cleaning the surface of the contact area were compared: a surface etch using diluted hydrofluoric acid ( $\text{HF}:\text{H}_2\text{O}$  1:10), a surface etch using diluted phosphoric acid ( $\text{H}_3\text{PO}_4:\text{H}_2\text{O}$  1:100), and an oxygen plasma discharge cleaning. Two main observations were made from these tests: first, cleaning the surface of the YBCO films by chemical etching was extremely detrimental to the bond strength. Second, for contacts fabricated after the  $\text{O}_2$  plasma cleaning, and as for those fabricated on magnetron sputtered samples, it was observed that the contact strength was inversely proportional to the amount of silver in the contact (see figure 5). Contact resistance measurements were performed (using a three-point-probe technique) and the resulting values are shown in table 1. These values are consistent with those reported by others (4).

For sputtered contacts consisting of 250 nm of silver followed by 250 nm of gold a contact "aging" effect was observed. Initial pull strength test with these contacts showed moderate pull strengths for both 0.7 mil gold wire bonds ( $\geq 2$  g) and for the 1x2 mil gold ribbon bonds ( $\sim 10$ -16 g). However, in subsequent tests made after 3 months of storage in a dry box the 0.7 mil wires could not be bonded to the contacts. No appreciable change was observed for the 1x2 mil ribbons. Auger analysis performed on these contacts (see figure 6) showed an intermixing of the gold and silver at the surface of the contacts instead of a layered gold/silver structure. The silver at the surface of the contact may be prone to oxidization and therefore prevent the formation of strong bonding for the 0.7 mil gold wire which is more sensitive to the contact surface properties due to its smaller bonding area.

Similar tests were performed in our laboratory with films on which metal contacts have been fabricated "in-situ" (i.e., immediately after film deposition and without exposure to the ambient). It was observed that for "in-situ" deposited gold contacts fabricated at

the JPL's Microdevices Laboratory (5), the bonding properties were excellent (18-20 g), consistently producing pull strengths far in excess of the MIL-STD requirements.

The space qualification process also required the performance of vibration tests on the complete downconverter submodule formed by the integration of the LO with a cryo-mixer onto a gold plated kovar subcarrier. Vibration tests were performed on two of these submodules at the NASA-Lewis' Structural Dynamics Laboratory, to test structural and functional integrity. Tests ran for a duration of 120 seconds in each of the three axes (i.e., x,y, and z). The frequency range was from 200 to 2000 Hz and the vibration level was 16.82  $G_{rms}$  for all three axes. This was a qualification test level of approximately 6 dB above the maximum expected flight environment. Subsequent inspection and testing showed that there was no damage to either component, providing confidence that the hardware was suitable for launch operations.

## CONCLUSIONS

A hybrid superconductor/semiconductor planar local oscillator circuit has been fabricated, tested, and space qualified. The oscillator was characterized as an independent component as well as incorporated into a full cryogenic receiver. It was observed that the superconducting films are extremely sensitive to the processing requirements involved in the fabrication of HTS-based components to the extent that finished components rarely have identical performance. Several contact processing techniques were considered to identify a process of producing low contact resistance as well as good bond strength. We found that the properties of the ohmic contacts, specifically strength, were dependent not only upon the type of contact and processing steps but also on the type of YBCO film employed. The presence of silver in the contact while providing acceptable contact resistance values was found to be detrimental to the contact strength. In contrast, in-situ deposited gold contacts were the strongest observed. Vibration tests of the oscillator/cryo-mixer downconverter submodule resulted in no damage to either component demonstrating that the hardware was suitable for launch operations.

## REFERENCES

1. Klieber, R., et al., IEEE IEDM, 36, 923 (1991).
2. Rohrer, N. J., et al., IEEE Trans. Microwave Theory Tech., 41, 1865 (1993).
3. Nisenoff, M., et al., IEEE Trans. Appl. Supercond., 3, 2885 (1993).
4. Dreuth, H., et al., Supercond. Sci. Tech., 6, 464 (1993).
5. Javadi, H. H. S., et al., Proc. SPIE, 2156, 101 (1994).

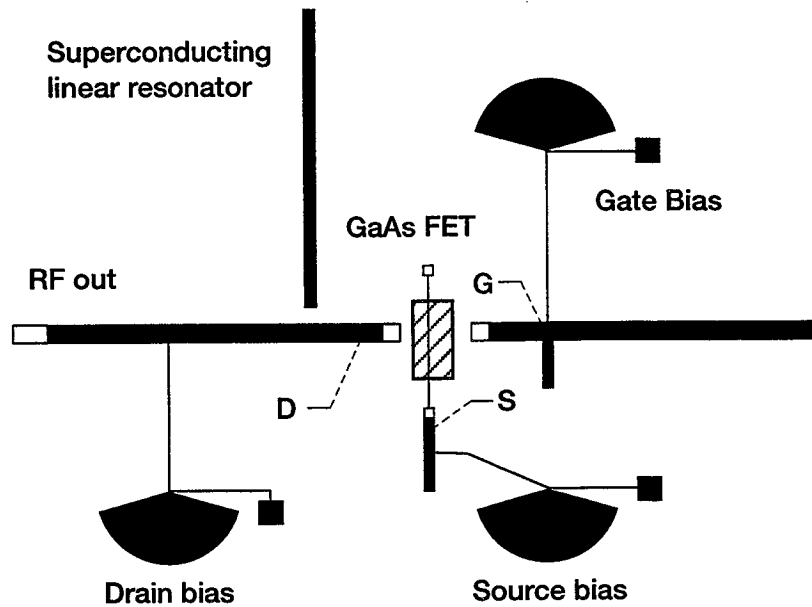


Figure 1.—Hybrid superconductor/semiconductor planar local oscillator. The resonator has a line width of 6.6 mil and a length of 173.5 mil. The bias lines are 1.7 mil wide.

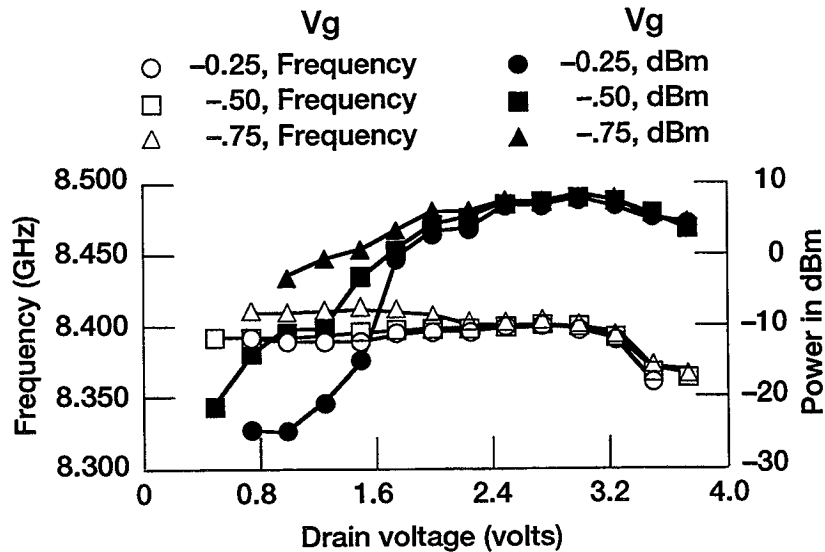


Figure 2.—Output power (in dBm) and frequency (in GHz) for the local oscillator versus drain voltage ( $V_d$  in volts) as a function of gate voltage ( $V_g$  in volts).

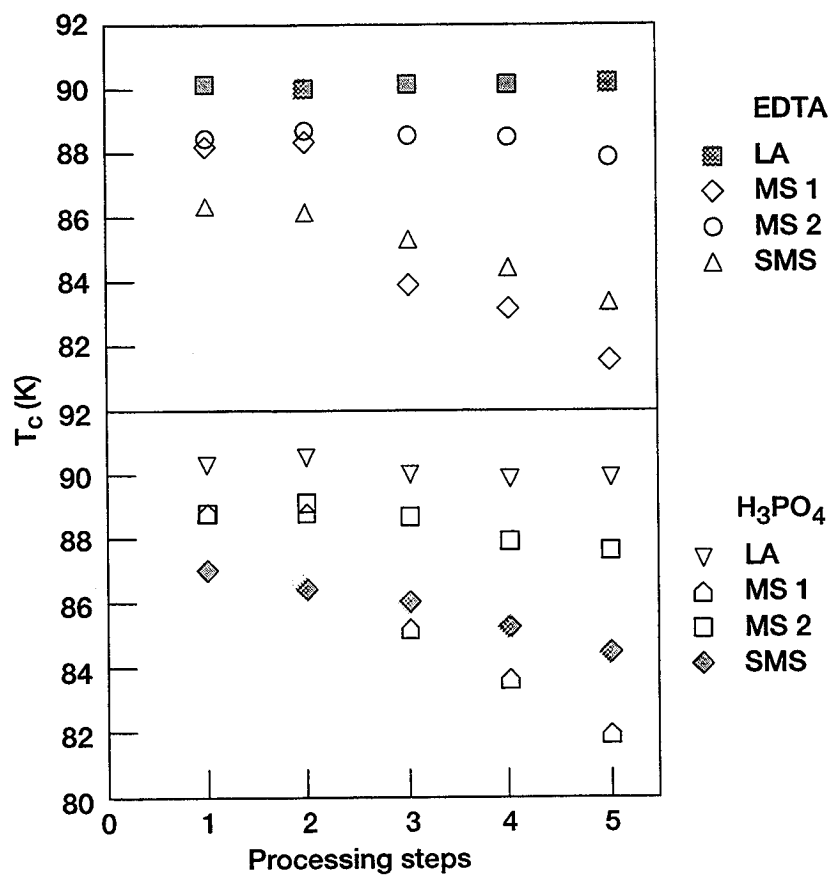


Figure 3.— $T_c$  versus processing steps for laser ablated (LA), magnetron sputtered (MS), and "smooth" magnetron sputtered (SMS) YBCO thin films on  $\text{LaAlO}_3$ . The processing steps are: (1) as received, (2) wet etching (either with EDTA or  $\text{H}_3\text{PO}_4$ ), (3) contact deposition and annealing, (4) epoxy cure cycle, (5) vacuum bake-out.



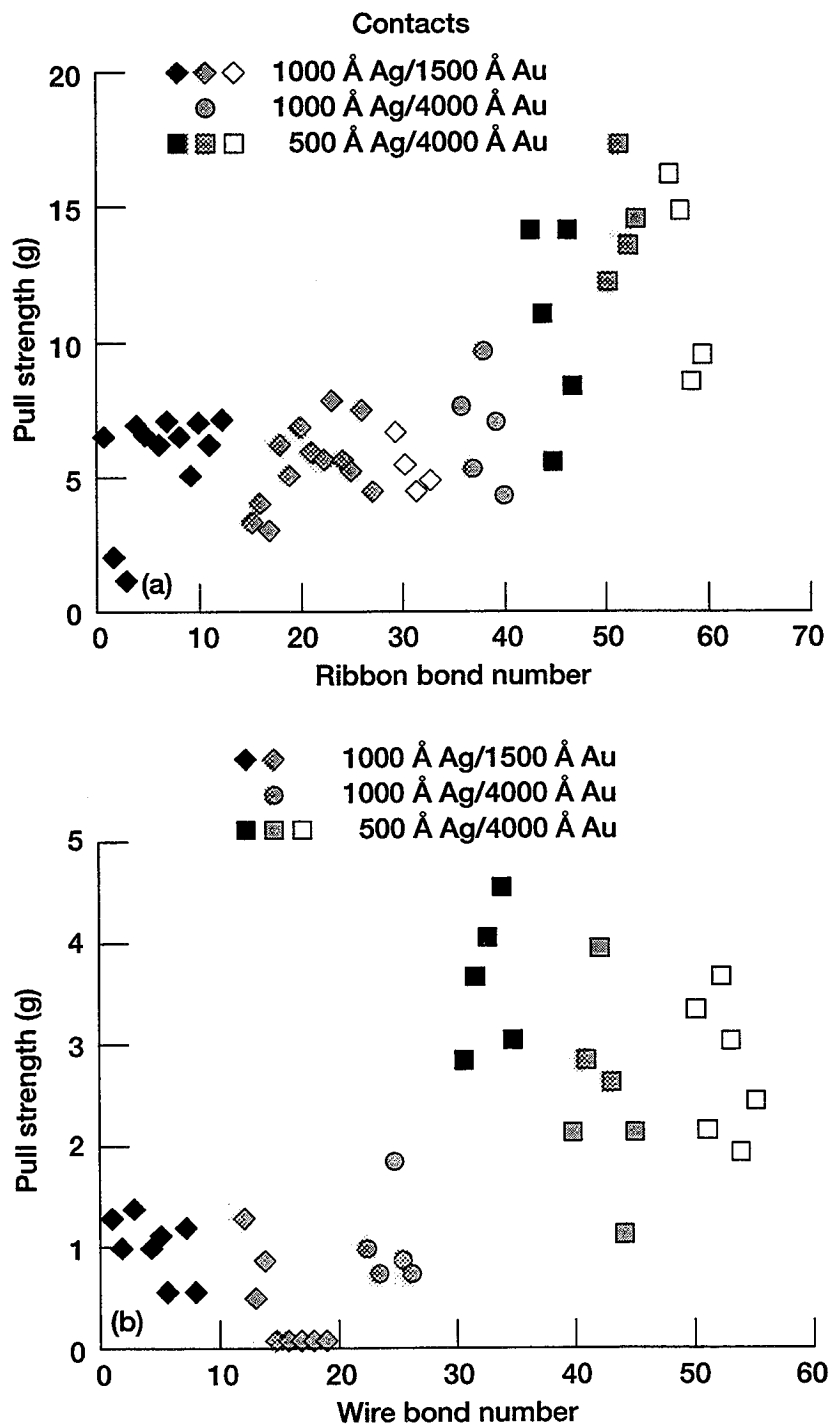


Figure 4.—Pull strength test for sputtered YBCO films.  
 (a) 1x2 mil gold ribbon. (b) 0.7 mil gold wire. Each shading  
 type corresponds to a different sample.

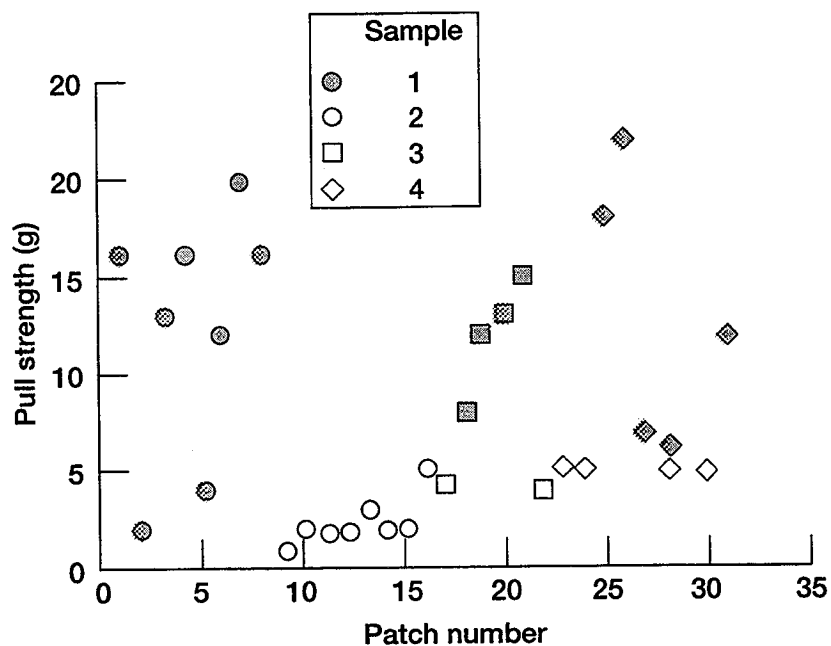


Figure 5.—1x2 mil gold ribbon pull strengths for laser ablated YBCO thin films. Open symbols are gold/silver contacts (4000 Å Au/500 Å Ag). Solid symbols are gold contacts. (4000 Å Au).

Table 1. Contact Resistance for Silver/gold and Gold Contacts

Temperature (K)	Silver/gold	Gold
77	$1.3 \times 10^{-6} \Omega\text{-cm}^2$	$9.1 \times 10^{-6} \Omega\text{-cm}^2$
10	$1.3 \times 10^{-6} \Omega\text{-cm}^2$	$2.8 \times 10^{-6} \Omega\text{-cm}^2$

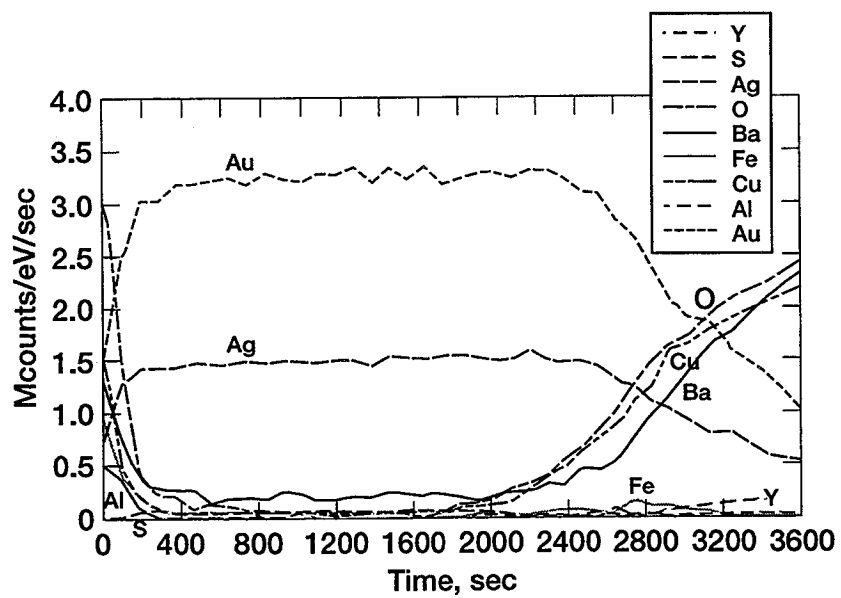


Figure 6.—Auger analysis of silver/gold (250 nm: 250 nm) contacts on YBCO.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE June 1995	3. REPORT TYPE AND DATES COVERED Technical Memorandum		
4. TITLE AND SUBTITLE Space Qualified Hybrid Superconductor/Semiconductor Planar Oscillator Circuit		5. FUNDING NUMBERS  WU-235-01-0A		
6. AUTHOR(S) F.A. Miranda, C.M. Chorey, R.R. Romanofsky, and K.B. Bhasin				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Lewis Research Center Cleveland, Ohio 44135-3191		8. PERFORMING ORGANIZATION REPORT NUMBER  E-9541		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  National Aeronautics and Space Administration Washington, D.C. 20546-0001		10. SPONSORING/MONITORING AGENCY REPORT NUMBER  NASA TM-106978		
11. SUPPLEMENTARY NOTES Prepared for the Low Temperature Electronics and High Temperature Superconductivity Symposium sponsored by the Electrochemical Society, Reno, Nevada, May 21-26, 1995. Responsible person, F.A. Miranda, organization code 5620, (216) 433-6589.				
12a. DISTRIBUTION/AVAILABILITY STATEMENT  Unclassified - Unlimited Subject Category 76  This publication is available from the NASA Center for Aerospace Information, (301) 621-0390.		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words)  We report on the space qualification of a hybrid superconductor/semiconductor planar local oscillator (LO) at 8.4 GHz. This oscillator was designed, fabricated, and tested as a component for the High Temperature Superconductivity Space Experiment II (HTSSE-II). The LO consisted of a GaAs MESFET and microstrip circuitry patterned onto a YBa <sub>2</sub> Cu <sub>3</sub> O <sub>7.8</sub> high-temperature-superconducting (HTS) thin film on a 1.0x1.0 cm <sup>2</sup> lanthanum aluminate (LaAlO <sub>3</sub> ) substrate. At 77K, this oscillator achieved power output levels of up to 10 dBm into a 50 Ω load. When incorporated into a full cryogenic receiver, the LO provided output powers within 0.0-3.0 dBm with less than 50 mW of dc power dissipation. Space qualification data on the sensitivity of the HTS films to the processing steps involved in the fabrication of HTS-based components are presented. Data on ohmic contacts, strength of wire bonds made to such contacts, and aging effects, as well as vibration test results are discussed.				
14. SUBJECT TERMS Local oscillator; Superconductor/Semiconductor hybrid circuit; YBCO HTS thin film; GaAs MESFET; Space qualification			15. NUMBER OF PAGES 12	
			16. PRICE CODE A03	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT	